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Characterization of coastal environment by means of hyper- and multispectral techniques

Andrea Ciampalini [a,*], Ilaria Consoloni [b], Teresa Salvatici [a], Federico Di Traglia [a,b], Francesco Fidolini [a], Giovanni Sarti [b], Sandro Moretti [a]

[a] *Earth Sciences Department, University of Firenze, Via La Pira, 4, 50121, Firenze, Italy*
[b] *Earth Sciences Department, University of Pisa, Via Santa Maria, 53, 56126, Pisa, Italy*

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ABSTRACT

The management of the coastal environment is a complex issue, which needs for appropriate methodologies. Erosional processes and longshore currents present in the submerged beach represent a serious danger for both people and human infrastructures. A proper integration between traditional and innovative techniques can help in the characterization and management of the beach environment. Several different multispectral and hyperspectral techniques were used to retrieve information about the hydro and morphodynamic settings of the Pisa province coast (Tuscany, Italy). Results were validated using about 130 samples collected along the study area, between the mouths of the Serchio river and the Scolmatore canal. The composition of sand samples was evaluated by means of petrographic microscopy and grain size analyses. The same samples were analyzed using an Analytical Spectral Device (ASD) Fieldspec. The obtained sediment spectral library was used to evaluate the differences in mineralogical composition, which can be related to different source areas. Results coming from spectroscopy were compared to those obtained from the petrographic and grain size analysis. Furthermore a multispectral aerial image was used to evaluate sediment distribution along the submerged beach, to map the geomorphic features and to detect the presence of longshore and rip currents. This works suggests that optical remote sensing technique can be profitably used in order to reduce the need for expensive and time consuming conventional analysis.

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Introduction

Coastal zones are very complex and dynamic environments, naturally subjected to recurring morphodynamics changes. However, due to the intensification of human-induced pressure the rate of change is increasing. The management and conservation of coastal areas are crucial, especially in areas where humans are present (Mc Kenna, O'Hagan, Power, Macleod, & Cooper, 2007; Stojanovic & Ballinger, 2009; Zacarias, Williams, & Newton, 2011). Understanding the natural processes characterizing the coastal zones and influencing their evolution is a key point for a proper territory management and planning (Dharmaratne & Braithwaite, 1998; El Mrini, Maanan, Anthony, &Taaouati, 2012; Manning, Wang, Valliere, Lawson, & Newman, 2002). Beaches represent a substantial source of income for their touristic attractive. It is worth noting that beaches are frequented by tens of millions of people worldwide (Lushine, 1991). This amount, combined with the risks related to the hydrodynamic setting, makes beaches locations with a high level of public risk. Among the hazards related to beaches, surf zone processes and beach morphology play an important role (Short & Hogan, 1994). The recognition of these hazards is fundamental to plan a correct management of the coast. One of the most common hazardous processes is constituted by rip currents, which act in the surf zone (Dalrymple, MacMahan, Reniers, & Nelko, 2011; Shaw et al., 2014; Short & Hogan, 1994). A prompt detection of this kind of currents, representing a lethal natural hazard, sensibly increases the beach safety level.

The understanding of the hydrodynamic conditions present along the shore is an important issue not only for people safety but also to protect the coastal environment from erosive processes, which lead economic loss in term of damages to properties and structures.

* Corresponding author. Tel.: +39 055 275748.
E-mail address: andrea.ciampalini@unifi.it (A. Ciampalini).

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A proper management plan of a coastal area must necessarily consider the dynamic processes responsible of the erosion and/or sediment distribution along the shore.

Coastal areas, characterized by the presence of several river mouths, are natural laboratories where the spatial and temporal variability of sediments distribution can be detected. River input of freshwater and/or flood events represent controlling factors on the dispersion and sedimentation dynamics (Kuenzer, van Beijima, Gessner, & Dech, 2014; Small et al., 2009). Several techniques were used and proposed to study the dynamic nature of coastal systems, especially for the determination of changing in shorelines, erosion, and deposition due to sediment transport (Anil Ari, Yüksel, ÖzkanÇevic, Güler, & YalçinerBayram, 2007; Baily & Nowel, 1996; Bertoni, Sarti, Benelli, Pozzebon, & Raguseo, 2010). The composition of clastic sediments is generally characterized by its physical features, chemical composition and petrographic composition (texture and mineralogy).The study of the compositional and textural variability of sediments provides information on the evolution of geography, climate, tectonics and lithology of the sediment source areas and on the dispersal pattern of sediments along the coast (Borges & Huh, 2007). The provenance of littoral sands can be studied though a variety of methods, including petrographic analysis, whole rock and mineral chemistry and radiometric dating. Usually these conventional methods are time consuming and expensive.

In contrast, remote sensing techniques represent inexpensive and fast methods and they are extensively used to monitor the coastal environment and the reflectance properties of sediments (Holman & Haller, 2013; Liu, Islam, & Gao, 2003; Power, Holman, & Baldock, 2011; Small et al., 2009; Teodoro, Pais-Barbosa, Gonçalves, Veloso-Gomes, Taveira-Pinto, 2011; Teodoro, Pais-Barbosa, Veloso-Gomes, & Taveire-Pinto, 2009; Xu et al., 2014). The sediment reflectance spectrum is strongly affected by its lithologic and/or mineralogic composition, grain size distribution and moisture. Furthermore, remote sensed (space-borne and air-borne) images can be suitably used to retrieve and map water characteristics (turbidity, water depth, quality, presence of algae), because these features affect the water optical properties (Liew, Chang, & Kwoh, 2012). Thus these techniques can be profitably used in the management of coastal environments, providing several useful information over wide areas.

The aim of this research is to evaluate remote sensing techniques to identify physic, morphologic and hydrodynamic features which characterize the coastal environment affected by erosive phenomena. Both traditional (grain size and petrographic analysis) and innovative (hyperspectral and multispectral) techniques were used and evaluated in order to provide suitable tools for the management of the coastal environment.

The study area

The study area, about 26 km long and it is comprised between the Serchio River and the Scolmatore canal outlets (Fig. 1). It belongs to the physiographic unit extending from Punta Bianca to the north and to the Livornesi Mountains to the south, covering a distance of about 70 km (Bertoni & Sarti, 2011). The entire coastal zone is characterized by an elevated anthropic pressure with the exception of the area comprised between the Arno River and La Bufalina (Fig. 1), which falls in the Regional park of Massaciuccoli-San Rossore. The coastal dune systems are mainly preserved within the park area. Three harbors (Fig. 1, Marina di Carrara, Viareggio and Marina di Pisa) strongly interfere with the littoral sedimentary drift triggering erosive processes or producing sandy accumulation down or up drift of the port respectively.

The coast is characterized by sandy beaches faced a wide coastal plain formed by Late Quaternary deposits and fed, from north to south by the Magra, the Serchio and the Arno rivers. The last two, and particularly the Arno river, feed the Pisa shoreline, even if in an insufficient way (Cipriani, Ferri, Iannotta, Paolieri, & Pranzini, 2001). Since Etruscan and Roman times, the Arno river delta progradation took place until the beginning of the second half of the nineteenth century, when erosive processes began (Amorosi, Rossi, & Sarti, Mattei, 2013). The degradation of the Arno river delta apex was induced by several factors (reclamation works, harbors, jetties, sandpits, river dams), which strongly changed the sedimentary budget (Pranzini, 1983; Rapetti & Vittorini, 1974). In particular, the retreat of the shoreline located north of the Arno river mouth exceeded 1000 m in less than 150 years and involved the S. Rossore beach (Fig. 1). To the south, the retreat was limited to approximately 300 m, due to the construction of protection structures (Aminti & Pranzini, 2000; Pranzini, 1989). This particular framework modified through time the natural sediment distribution along the coast modifying the natural shore feeding processes. Shore protections at Marina di Pisa were recently enhanced also by the creation of artificial gravel beaches, which allowed the reduction of invasive approaches to coastal defense and a better exploitation of the shore from a touristic point of view (Bertoni et al., 2010; Bertoni, Sarti, Benelli, Pozzebon, & Raguseo, 2012; Bertoni et al., 2013).

The study area is characterized by a littoral drift (Fig. 1) directed to the north between the Arno river outlet and Forte dei Marmi and to the south between the Arno River and the village of Calambrone, which represents a convergence zone (Aiello et al., 1976; Gandolfi & Paganelli, 1975; Pranzini, 2004).

The climatic setting is dominated by westerly winds, which usually generate seasonal mild storms, whereas southwesterly winds show the highest velocities causing the most strongest and destructive storms (Bertoni & Sarti, 2011). Tidal influence is almost negligible, reaching a maximum excursion of 30 cm (Cipriani et al., 2001).

Methodology

In situ analysis

Sampling sites are located along 50 transects arranged perpendicular to the coast (Fig. 2). For each site about 1 kg of sediment was collected. Sample positions were located with a differential GPS receiver. Samples were systematically collected at: −9/−10 m (A); −7/−8 m (B); −5/−6 m (C); −4 m (D); −3 m (E); −2 m (F); −1 m (G); swash zone (H); backshore 1 m (K) and 2 m (L). A subset of 70 samples was chosen for a preliminary analysis. Samples were dried and split. A fraction of each sample was used for petrographic and grain size analyses. The organic fraction was removed using hydrogen peroxide. Samples for petrographic analysis were sieved considering only the fraction between 2 mm and 63 μm. The petrographic analysis was performed following the Gazzi-Dickinson method (Dickinson, 1970; Gazzi, 1966; Ingersoll et al., 1984) using 6 classes: quartz; feldspar; plagioclase; lithic grains; mica and carbonates (Dickinson & Suckzek, 1979; Graham, Ingersoll, & Dickinson, 1976; Zuffa, 1980, 1985). For the grain size analysis, 7 classes were defined: gravel (>2 mm); very coarse sand (1–2 mm); coarse sand (0.5–1 mm); medium sand (0.25–0.5 mm); fine sand (125–250 μm); very fine sand (62.5–125 μm) and silt and clay (<62.5 μm).

Hyperspectral analysis

An Analytical Spectral Device (ASD) Fieldspec spectroradiometer was used to collect the samples spectra. This sensor measures reflectance in 3–10 nm bandwidths over the

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